Smart Houses for Energy Efficiency and Carbon Dioxide Emission Reduction

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***Abstract*—Understanding the energy consumption of households is a cornerstone for improving residential energy efficiency. In addition, the CO_2 emission profile of energy consumption must be fully understood, to achieve the decarbonisation of energy sector in Europe. Smart houses incorporated into smart grids allow the survey and control of household energy consumption. In this article, the electricity consumption and its related CO_2 emissions are studied for a typical Finnish household. A model detached house is used to simulate the effect of home automation, designed to optimize energy usage, on the CO_2 emissions of this household. Hourly electricity production data are used with an hourly electricity consumption profile generated using fuzzy logic. CO_2 emissions were obtained from the monthly and weekly electricity generated data. The CO_2 emissions related to the use of electric appliances represent around 543 kg_{CO2}/y per dwelling when considering the electricity generated only, and 335 kg_{CO2}/y when balancing the emissions with the exported and imported electricity. Home automation reduced the CO_2 emissions by 13 %. Part of emission reduction was achieved through peak shifting, by moving energy consumption load from daytime to night time. This paper aims at highlighting the role of home automation in reducing CO_2 emissions of the residential sector in the context of smart grid development.**

Keywords-CO_2 emissions; Home Automation; Load shifting; modelling;

I. INTRODUCTION

In December 2013, the European Commission has set clear goals in its Energy Roadmap 2050 (COM(2011)885/2), to achieve a decarbonised society. Decarbonisation in this context means reducing greenhouse gas emissions to 80 % - 95 % below 1990 levels by 2050. This will provide considerable challenges for electricity production, consumption and management. Smart grids represent one tool for achieving this target. Smart grids aim at increasing the energy efficiency of the network, peak load shaving, load shifting, and reduction of energy consumption. Smart buildings are expected to be an integral part of smart grids, with smart meters as the gateway allowing the entrance of smartness into the building. Smart meters receive and send information to and from the building for use such as in Home Area Networks, and Grid handling.

The massive deployment of smart meters under way in Europe facilitates digital measurements, and will allow a consequent access to energy consumption data to energy companies and authorities. European Union (EU) Member States have the obligation of implementing smart meters covering 80 % of consumers by 2020 at the latest [1]. In contrast to the European Energy Efficiency Directive (2012/27/EU) [1], the Finnish Electricity Market law 588/2013 and its application Act 2009/66 on the electricity supply in the survey and measurement sets the deadline of 2014 [2]. Legal obligations to increase energy efficiency also provide a motivation to the deployment of renewable energy sources (RES) as a vector for energy production, both electrical and heating, in a large scale as well as in the buildings. Home energy management can have a significant role in contributing to energy efficiency and cutting or shifting peak load. This can be achieved through an active collaboration of energy consuming systems and the information network on a local level [3]. Putting together the different factors, smart grids, smart building, RES-based heat and electricity and energy efficiency, involve the development of a smart energy network (SEN), capable of managing the energy system through constant monitoring.

The impact of energy efficiency on emissions from the residential sector has been a subject of much research [4]. It has been shown that electric load shifting from the residential sector may reduce air pollution in urban areas [5]. To this effect, developing mathematical tools that are able to anticipate and cut emissions through the deployment of smart systems and home automation is of major importance.

This article aims at exploring the significance of home automation and its impact on the carbon emissions of dwelling, and the possible ways home automation can contribute to decarbonisation. In the first section of the paper, a description of the CO_2 emissions from the production and the use of electricity in Finland will be presented. The second section presents the methodology used for translating hourly carbon emissions to single households will be described. The third section shows and details the results from the simulations carried out on two chosen type of dwelling which will be described and analysed.

II. RELATED RESEARCHES

Researches on smart houses and their development have been going on for quite some times. Smart homes can be broadly seen as a building monitored and controlled for multiple purposes [6]. The energy management feature taken in charge by the smart home is one aspect that has

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been developed. Algorithms for generating electricity consumption load profile have been developed on an hourly and half-hourly basis [7], but also with a finer grid on a minute-basis [8]. These algorithms can be further used to emphasise the potential of energy smart houses and their roles in improving the energy efficiency, reducing the energy consumption, and reducing the carbon emissions from the energy used. More elaborated algorithms have been developed where the integration of each appliance within the dwelling have been modelled [9], [10]. Finally, the management of appliances within the dwelling may as well be implemented in simulation for optimizing their usage and enhancing demand-side management [11], [12].

Previous studies have attempted to measure the impact of energy efficiency measures on the CO_2 emissions from the residential sector [4]. Detailed algorithms for evaluating the CO_2 emissions from appliances usage have been proposed [13]. One of the main drawbacks of the previous methods is that the carbon emissions are based on a fixed coefficient, thus limiting the understanding of the CO_2 emissions mechanism. A more dynamic model has been elaborated for estimating the CO_2 emissions and their impact on demand response [14]. Although the last research has based its dynamism on real dataset of energy production on an hourly basis for various countries, the CO_2 emissions related to the production of electricity is based on the IEA annual report on CO_2 emissions [15]. Consequently, studies on segmented electricity production, related CO_2 emissions, and the impact of home automation on the emissions are lacking.

III. ELECTRICITY CONSUMPTION AND CARBON EMISSIONS IN FINLAND

The role of the residential sector in reducing carbon emissions is paramount in the development of the future smart grid [16]. In terms of CO_2 emission reduction in the residential sector, the largest effort should be made in retrofitting buildings. The average renewal time of the residential sector is estimated to be around 70 years [4]. The influence of technology on CO_2 emissions needs to be highlighted. Consequently, technology upgrading can greatly influence the total CO_2 emissions of the residential sector. In Finland, lighting consumes over 30 % of the total electricity used in households for appliances [17]. The upgrade of lighting technology is one way for impacting energy consumption [9], but also for reducing carbon emissions [18]. Furthermore, home energy management systems will continue to play a role for increasing energy efficiency, reducing energy consumption [19] and allow load shifting.

Electricity generation and consumption is being constantly surveyed, recorded and reported by the Official Statistics of Finland. In 2012, household appliances consumed 8 072 GWh of electricity [17]. At the same time, 2 579 781 households were registered in Finland [20], resulting in an average consumption of 3 129 $kWh/y.dw^{-1}$. There can be considerable deviation from this average value, if the households is in an apartment building or a detached house [21]. Furthermore, the total electricity production in Finland was around 67.7 TWh in 2012, while the total consumption of electricity was around 82.9 TWh, and a total of 8.4 $MtCO_2$ were emitted. Therefore, it can be estimated that the share of electricity using devices in the total CO_2 emissions from electricity production and use are 1001 tCO_2/GWh_{pro} or 817 tCO_2/GWh_{cons}.

IV. METHODOLOGY

A. Electricity consumption profile

The house electricity demand profile is drawn on an hourly basis using different components for evaluating the electricity consumption from appliances, without primary and secondary electric heating systems. Two dwellings will be studied: one having home automation and one without home automation and the difference in their CO_2 balance will be evaluated.

The modelled house contains twenty-one appliances, all of them labelled A or B [9]. The house being in Finland, one of the appliances is an electric sauna stove. The sauna stove used for the modelled house was set to be 6 kW. The overall electricity consumption of appliances in this modelled house is 4 501 kWh/y, which correlates with the findings of the European ODYSSEE MURE project and that of the Sähkötohtori Analysis [21]. The measured data were obtained from detached houses in Oulu, Finland, which were equipped with a 10 kW sauna stove.

B. Hourly electricity generation and emissions

Data acquisition consisted of analysing the electricity generation of all power plants in Finland and the categories of power plants on an hourly basis. Secondly, the carbon dioxide emissions associated with the aforementioned categories were calculated on an hourly basis. Monthly CO_2 emissions are available from July 2007 to October 2013 [22]. It is then possible to evaluate the CO_2 emissions on an hourly basis by associating both elements, the primary energy source for electricity generation and the associated monthly CO_2 emissions.

The electricity generated in Finland on an hourly basis is reported by the Finnish Transmission Service Operator – Fingrid since 2004 [23]. The data is split into two groups: the electricity generated from the power plants and the electrical load on the network taking into consideration the import and export of electricity. Moreover, the Finnish Industry Association (Energiateollisuus) recorded the weekly electricity generated from 1990 [24], which has been broken down between the energy technology used for producing the electricity: wind, hydropower, nuclear, CHP Industry, CHP district heating, conventional and gas turbine power plant. Finally, Fingrid informs in real-time the state of the network using the same categories as mentioned above. Thus, for building up the hourly electricity generation by categories for the year 2012, the weekly average electricity production by category is used in parallel with the hourly electricity generated countrywide. The exported electricity is considered in the electricity generated and in the corresponding CO_2 emissions. The imported electricity is considered as a share of the CO_2 emissions from electricity consumption in Finland. In order to include the imported electricity into the overall emissions from electricity consumption in Finland, it is necessary to know the energy mix for producing the electricity of the country from which Finland is importing. The hourly electricity generated from a particular energy source in the primary country is evaluated using (1). The notation *h, w*, and *m* designate the hourly, weekly, and monthly time step respectively, *i* is the energy technology used for producing the electricity, and *tot* stands for the total amount of a unit countrywide.

$$P_{h,i} = \frac{P_{w,i}}{P_{w,tot}} \cdot P_{h,tot} \qquad (1)$$

Where $P_{h,i}$ is the electric energy generated by a given technology per hour [MWh/h], $P_{w,i}$ is the electric energy generated on a weekly basis by a given technology [MWh/w], $P_{w,tot}$ is the total amount of electricity produced in Finland per week [MWh/w], and $P_{h,tot}$ is the total amount of electricity produced per hour [MWh/h].

Once the hourly electricity generated by technology has been defined, it is possible to evaluate the hourly emissions from the power plant park.

C. *The CO_2 emissions from power plants*

As part of the its legal obligation, Finland is publishing the CO_2 emissions from power plants, and every energy intensive industry reports its expected and measured CO_2 emissions for each site [25]. The Finnish Industry Association estimates monthly specific emissions related to electricity production, based on the type of fuel used by the energy industry [24]. By knowing the hourly electricity production from each sector, it results in estimating the CO_2 emissions for each hour countrywide using (2) to (5).

$$E_{w,i} = a \cdot \left(\frac{P_{w,i}}{P_{m,i}} \cdot \frac{\delta_m}{7} \right) \qquad (2)$$

Where, *a* is evaluated using (3) if the full week is within the same month *n*, or (4) if the full week is between two months, *n* and *n+1*.

$$a = \frac{7E_{m,n}}{\delta_m} \qquad (3)$$

$$a = \left(\delta_w \cdot \frac{E_{m,n}}{\delta_m} \right) + \left(\frac{E_{m,n+1}}{\delta_m} \cdot (7 - \delta_w) \right) \qquad (4)$$

Thus, the hourly emission is given by,

$$E_{h,i\text{-}gen} = \frac{P_{h,i}}{P_{w,i}} \cdot E_{w,tot} \qquad (5)$$

Where $E_{h,i\text{-}gen}$ is the total emissions from the electricity generated hourly [$ktCO_2$/h], and $E_{w,tot}$ is the total weekly emissions for all power plants [$ktCO_2$/m], δ_w is the day number within a week where Monday is 1 and Sunday is 7, δ_m is the number of days in the studied month, $E_{m,n}$ is the monthly CO_2 emissions for the month *n*. Fig. 1 (a) illustrates the energy generated and its corresponding CO_2 emissions on an hourly basis for the year 2012 in Finland. It can be noticed that, although there is a strong correlation of CO_2 emissions to electricity generation, emissions may decrease even though the energy generation increases, due to the fact the energy mix is changing Fig. 1 (b).

The emissions due to the electricity imported are further implemented to the primary emissions from the electricity generated within the country. The CO_2 emissions from the electricity generated dedicated to the export is further subtracted from the hourly emissions $E_{h,c1}$. In order to account the total CO_2 emissions from the electricity load in the country, the emissions from each country with which Finland is trading electricity are evaluated, meaning Norway, Sweden, Russia and Estonia. As the hourly energy mix is not known for each country, a general coefficient of CO_2 emissions has been considered for each country named

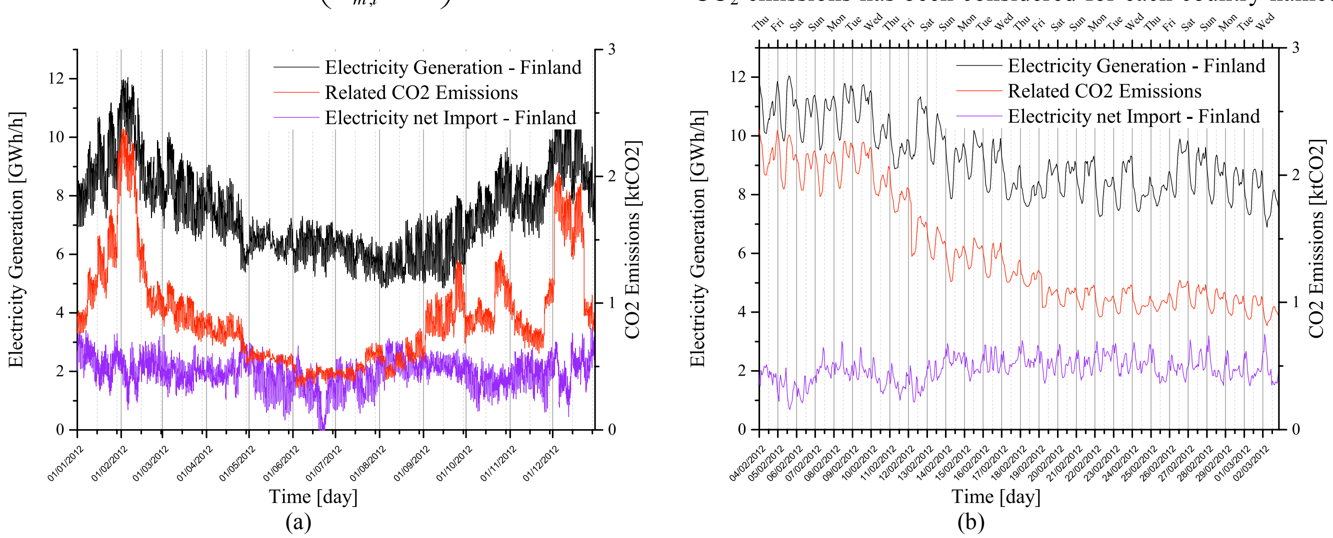

Figure 1. Hourly electricity generation, net import and their related CO_2 emissions in (a). 2012, and (b). from 4.02-02.03.2012.

previously, respectively 30, 17, 384 and 1 014 $kgCO_2/MWh_{pro}$ [15].

The share of CO_2 emissions coming from each trading country is evaluated using (6).

$$E_{h,c_n} = \sum_{n=2}^{n} \frac{P_{h,net-c_n}}{P_{h,load}} \cdot E_{c_n} \tag{6}$$

Where, $E_{h,cn}$ is the hourly emissions for each participating country to the electricity trade [$kgCO_2/h$], $P_{h,load}$ is the hourly electric load on the Finnish network [MWh/h], $P_{h,net-cn}$ is the net balance of electricity traded between Finland and the country n [MWh/h] in case of export or the difference between the electricity generated and the electricity exported in the case of Finland, and E_{cn} is the coefficient of CO_2 emissions for the corresponding country [$kgCO_2/MWh$]. In case $P_{h,net-cn}$ is negative, the coefficient of CO_2 emissions is equal to $E_{h,i-gen}$ as the emissions from the Finnish production is exported as well, otherwise, E_{cn} takes the value defined by the IEA.

Finally the hourly emissions E_h are determined as the sum of the hourly emissions for each participating country to the electricity trade $E_{h,cn}$ as shown in (7).

$$E_h = \sum_{n=1}^{n} E_{h,c_n} \tag{7}$$

The emission data in Fig. 1 are then translated to a single household where the hourly electricity consumption profile has been previously generated using (8).

$$E_{h,house} = \sum_{j} \frac{P_{j,house}}{P_{h,tot}} \cdot E_h \cdot 10^3 \tag{8}$$

Where $E_{h,house}$ is the hourly emissions from the household [$kgCO_2/h$], and $P_{j,house}$ is the total hourly electricity consumed by the household excluding the electric heating [kWh/h]. Two cases are differentiated: CO_2 levels towards the production of electricity within the primary country, the net CO_2 emissions level considering the import and export as presented in this section. In the first case, P takes the value of the total electricity produced in the primary country $P_{h,tot}$. In the second case, P takes the value of the total load on the electric grid of the primary country $P_{h,load}$.

The results give an estimate of CO_2 emissions related to the electricity consumption in a private household on an hourly basis. This model is then applied to the previously modelled dwelling in order to estimate the daily CO_2 emissions from an average Finnish dwelling.

V. RESULTS AND DISCUSSION

The model showed that the CO_2 emissions are highly dependent on electric consumption levels. Depending on the energy mix for electricity production at a given time, CO_2 emission levels may be lower at peak hours and thus not proportional to consumption levels. Two models have been developed. In the first case, the CO_2 emissions from the dwelling are accounted relatively to the electricity production only. In the second case, the CO_2 emissions from the dwelling are balanced with the electricity exported and imported. Fig. 3 represents the energy consumption for the two modelled dwellings with home automation (Fig. 3 (a)), and without home automation (Fig. 3 (b)). The electricity consumption shown was extracted for a randomly selected week in May 2012, starting on Monday, the 23rd of May.

A. Case 1: Emissions related to the electricity production

These dwellings are similar in their characteristics e.g. number and types of appliances, number of inhabitants, dwellings dimensions, or users' habits. The CO_2 emission levels vary from 0.06 to 0.20 $kgCO_2.kWh^{-1}$. The levels depend on the energy mix of Finland's electricity generation. Consequently, the emissions from the dwelling, on an hourly basis, peak at 1.93 $kgCO_2.h^{-1}$ for the dwelling without home automation and 1.81 $kgCO_2.h^{-1}$ for the dwelling with home automation. In the first peak emission case, the related energy demand was 10.03 $kWh.h^{-1}$ and, in the second peak emission case, 9.42 $kWh.h^{-1}$. The maximum electricity consumption in the first case is 12.33 $kWh.h^{-1}$, and 10.16 $kWh.h^{-1}$. The emission peaks are somewhat related to the level of electricity consumption but also to the energy mix for electricity generation at the same time. The use of home automation may reduce the instantaneous peak of CO_2 emissions. The daily electricity profile of the dwellings and CO_2 balance between the two dwellings are represented in Fig. 3 (c).

The difference in the profile of the two modelled dwellings result in a 592 $kWh.y^{-1}$ reduction of total electricity consumption. In terms of CO_2 emissions, the dwelling that is not equipped with a home automation emits 543 $kgCO_2.y^{-1}$, while the house with home automation emit 473 $kgCO_2.y^{-1}$. The amount of CO_2 saved represents 12.78 % of original emissions.

The home automation shifted some of the electricity consumption from the evening peak to the night. It resulted in a decrease of the CO_2 emissions in the evening down to 37 % from the original level, and an increase of 51 % of CO_2 emissions overnight (Fig 3. (d)). Considering, however, that the emissions overnight are about 0.1 $kgCO_2.h^{-1}$ on average,

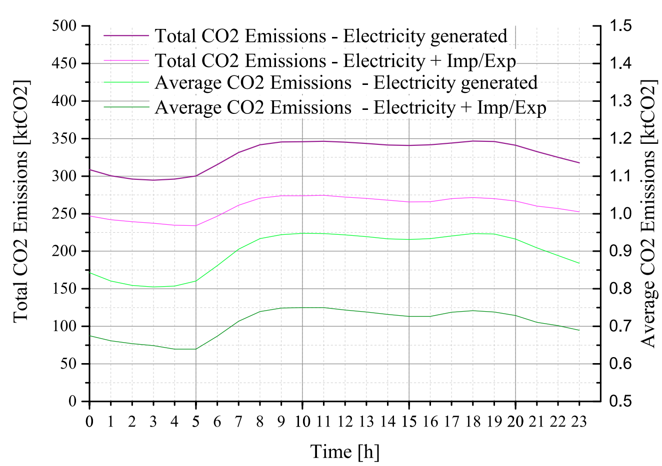

Figure 2. Total and average daily profile of the carbon dioxide emission in 2012, Finland

this can be regarded as relatively small cumulative amount. The emissions increased overnight by 3 to 5 $kgCO_2$, and reduced by 17 $kgCO_2$ on average over the whole year during the evening.

While the home automation was not optimised for reducing CO_2 emissions but for cutting the building peak load consumption, it resulted in the decrease of CO_2 emissions that relates to the electricity consumption. Notwithstanding, it is to be seen that the emissions related to electricity generation countrywide vary throughout the day. Fig. 2 represents the summed CO_2 emissions per hour on the left axis and the hourly average profile of CO_2 emissions on the right axis for the year 2012 from the electricity produced in Finland.

The CO_2 emissions during the peak hours are 0.95 $ktCO_2.h^{-1}$ on average, and correspond to a total of 346 kt_{CO2} between 6 and 7 pm. The lowest point on the daily plot of CO_2 emissions occurs around 2 and 3 am, with an average emission of 0.8 $ktCO_2.h^{-1}$ and a corresponding emission for this particular hour throughout the year of 294 $ktCO_2$.

B. Case 2: Emissions related to the net load

The CO_2 emissions in this 2nd case were found much lower than in the first case. Firstly, the total CO_2 emissions factor $E_{h,i\text{-}gen}$ has slightly decreased. This can be interpreted as an improvement in the global CO_2 emissions from the electric load at the country level. This is explained by the fact that Finland is mostly importing its electricity from Sweden and in second place from Russia. Norway and Estonia represents a small share of the electricity trade. On the one hand, Sweden has an average emission factor around 7 times smaller than the one of Finland, and on the other hand, Finland is exporting electricity with a high emission factor. Also, as the emissions from the Finnish electricity has been calculated for every hour, it introduce some peaks of CO_2 emissions while the electricity from the surrounding countries are applied a constant factor, thus bring a bias result. Nevertheless, the exchange of electricity is beneficial for Finland in terms of CO_2 emissions. The same dwellings that the one mentioned in case 1 were found to have 335 $kgCO_2.y^{-1}$ in case the home automation was not simulated, and 293 $kgCO_2.y^{-1}$ when home automation was running. For both dwellings, the difference between case 1 and 2 is around 38 %. This shows that the CO_2 emissions can be interpreted very differently depending on whether the

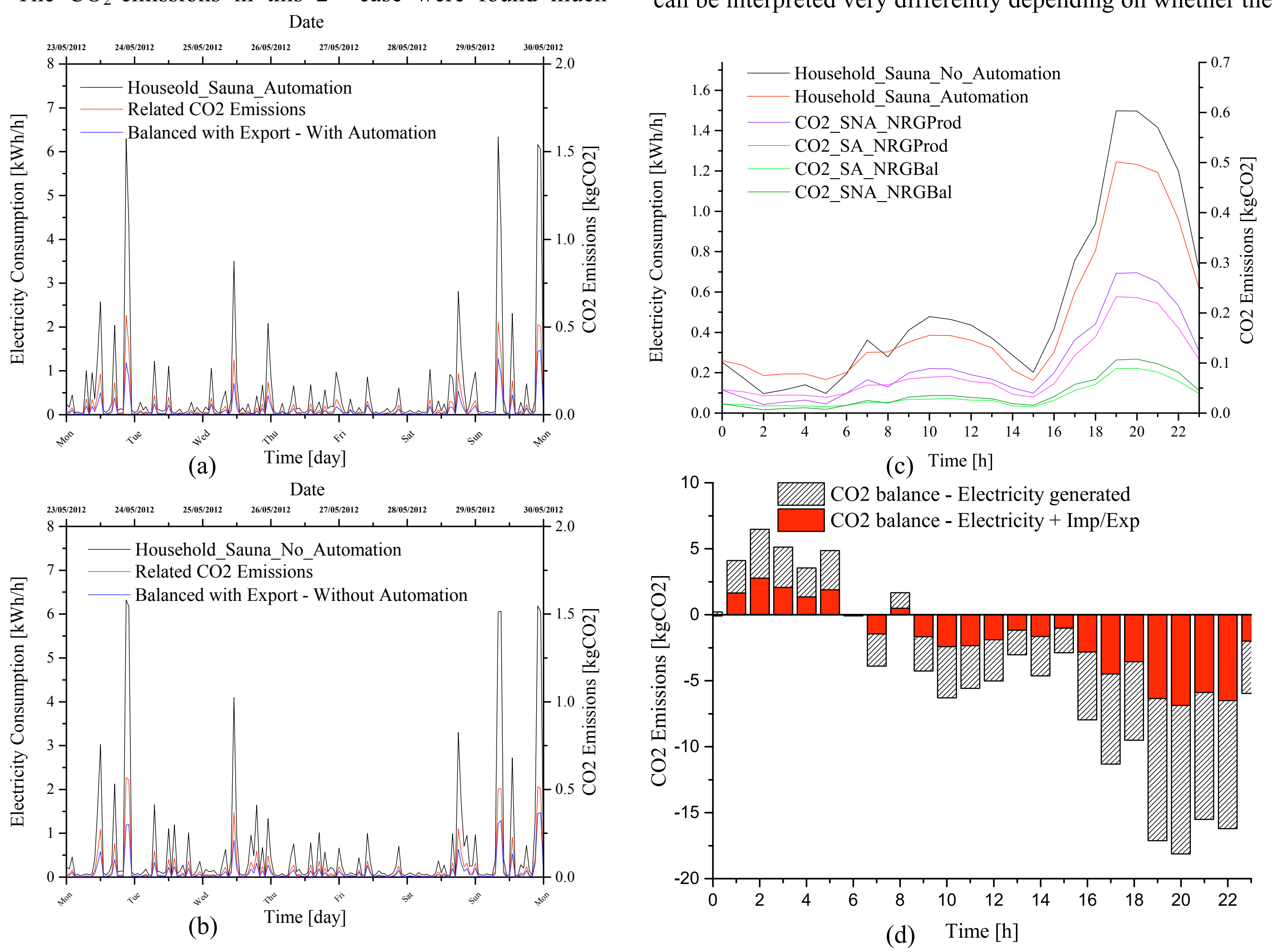

Figure 3. Electricity consumption with its related CO_2 emissions for (a) a dwelling with automation and (b) a dwelling without automation, (c) Daily electricity consumption profiles and (d) its related CO_2 emissions balance between 2 dwellings.

produced electricity, dedicated to the export, is subtracted from the overall electricity consumption of the country or if it should be included into the total CO_2 emissions.

Similarly, the peak of CO_2 emissions due to the electricity consumption in the dwellings are reduced compared to the Case 1 by 24 %. In the Case 2, the peak of CO_2 emissions for the dwelling without home automation reach 1.46 $kgCO_2$/h, and 1.37 in case the home automation is running in the dwelling.

At the system level, the total and average hourly CO_2 emissions have decreased as well. In case the exported and imported electricity are accounted in the total emissions, the low peak occurs between 4-5 am with an average emissions of 0.64 $ktCO_2$ and the high peak period occurs between 10-11 am with an average emissions of 0.75 $ktCO_2$ and cumulates 275 $ktCO_2$ for the same hour.

Regarding the shift of CO_2 emissions due to the home automation device and the feedback strategies used for informing the private consumers, it has decreased by 6 $kgCO_2$ in the evening and has risen by 2.7 $kgCO_2$ in the night time. The quantities of CO_2 shifted, presented in Fig. 3 (d), are different from Case 1 to Case 2 as the CO_2 emission profile for both cases are different, as shown in Fig. 2.

C. Discussion

Both cases showed that load shifting can contribute to 12.7 % decrease in CO_2 emissions. However, there is a difference depending if the balance of import and export is considered.

As well, consumer awareness and their willingness to comply is also a factor in the potential for reducing CO_2 emissions. Table 1 summarises the results from the CO_2 emissions and the electricity consumption from both dwellings.

It is necessary to point out the importance of methods evaluating emissions on the results. It is paramount that the countries involved use the same methodology for their CO_2 evaluation. In this study, Finland is mostly importing electricity from Sweden and Russia and exporting to Norway and Estonia. For Sweden, it results in importing "polluted" electricity and exporting cleaner electricity to Finland. Consequently, for Finland, the shifting of CO_2 emissions is greater when relating the emissions to the gross electricity production. Multi-objective algorithms will need to be developed for optimising electricity consumption and/or CO_2 emissions. In addition, an added level of complexity is if export/import net emissions are considered or not.

TABLE I. CO_2 EMISSIONS SUMMARY FOR THE TWO STUDIED CASES

	CO_2 emissions relative to		
	Electricity produced	***Net electricity consumed***	***Unit***
Min. $E_{h,i\text{-}gen}$	0.06	0.04	$kgCO_2$/kWh
Max. $E_{h,i\text{-}gen}$	0.20	0.19	
Max $E_{h,house}$ SA	1.81	1.37	$kgCO_2$/h
Max $E_{h,house}$ SNA	1.93	1.46	
Max $P_{j,house}$ SA	12.33	12.33	kWh/h
Max $P_{j,house}$ SNA	10.16	10.16	
Total $E_{h,house}$ SA	543	335	$kgCO_2$/a
Total $E_{h,house}$ SNA	473	293	
Max Average $E_{h,i\text{-}gen}$	0.95	0.75	$ktCO_2$
Min Average $E_{h,i\text{-}gen}$	0.8	0.64	
Max Sum $E_{h,i\text{-}gen}$	346	275	
Min Sum $E_{h,i\text{-}gen}$	294	234	

VI. CONCLUSIONS

The article detailed the CO_2 emissions of electricity generation in Finland. Firstly, monthly and weekly data of electricity generation were used to calculate corresponding CO_2 emissions into hourly data. This was used to evaluate the CO_2 emission profile of households. The model was based on hourly electricity load profiles previously built.

Secondly, the CO_2 emissions associated with imported and exported electricity generation were accounted as well. Both cases show the same peak distribution in their daily profile. Notwithstanding, emissions will depend on the fuel used at a particular hour. Therefore, the relationship between electricity production, import and export is not straightforward. The cumulated carbon emission overnight from the electricity produced in Finland stands at around 290 $ktCO_2.h^{-1}$, while the peak reaches 345 $ktCO_2.h^{-1}$. Considering the import and export of electricity, and their related CO_2 emissions, the peak dropped to 230 $ktCO_2.h^{-1}$ overnight, and the high peak at 275 $ktCO_2.h^{-1}$, respectively.

Although the home automation has not been optimised for reducing the CO_2 emissions from the modelled household, the CO_2 emissions from the electricity consumption are somehow proportional to electricity consumption levels. The study showed that home automation might reduce the carbon emission by 12.7 % while influencing the private consumers' everyday routine. The CO_2 emissions have been reduced most substantially during the evening peak, by 18 $kg_{CO2}/h.y^{-1}$ in the first case and by 6 $kg_{CO2}/h.y^{-1}$ in the second case, while the emissions at night time have increased from 3 to 5 $kg_{CO2}/h.y^{-1}$ on average. Although the CO_2 emissions related to electricity consumption from appliances are strongly correlated, the energy mix for producing this electricity needs to be considered and thus optimised for reducing the carbon footprint of households.

Consequently, smart buildings within a smart grid may not only participate to load shifting, increase energy efficiency or decrease in electricity consumption, but can also contribute significantly to the reduction of CO_2 emissions. It will, in turn, impact the total CO_2 emissions of the country and will assist in achieving the decarbonisation goal of the EU.

This limitation of this research is that there was no information available on the variation of the energy mix from the exporting countries, therefore, the import electricity had to be considered with a yearly constant CO_2 emission factor. Secondly, in the case of Finland, a more detailed estimation would require knowing the energy mix hour-by-hour, rather than estimating it from the monthly average.

Further research will investigate the impact of private consumers in correlation with home automation for reducing the CO_2 emissions of households. In addition, a full assessment considering district-heating systems shall be done, in order to achieve full integration of smart buildings in a smart energy network. Finally, the multi-objective algorithms will have to be further developed.

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